Quantifying isentropic transport in the middleworld using tracer-tracer correlations and a simple mixing model

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INTRODUCTION

Water vapor plays a crucial role in the upper troposphere and lower stratosphere (UT/LS) because of its impact on the radiative balance of this region and on the chemistry associated with polar ozone loss. Convection, subsidence of dry air from aloft, and isentropic mixing have been proposed as transport mechanisms of air to the UT/LS. The CRYSTAL-FACE campaign provides a unique and comprehensive set of measurements to study the impact of convection, in particular, on upper tropospheric humidity in the subtropics during the summertime.

We hypothesize that during certain flights transport of air into the middleworld (365-390 K) in the subtropics is dominated by quasi-isentropic transport of air coming not only from the upper tropical troposphere (UTT) across the subtropical tropopause (pathway 4, Figure 1), but also from the northern mid-latitude lowermost stratosphere (pathway 3, Figure 1). Several climatological studies (Dunkerton, 1995; Dethof et al., 1999) have shown that air parcels can travel equatorward in the lowermost stratosphere when they are influenced by monsoon regions or large scale quasistationary anticyclones. During these flights, diabatic descent from the tropical stratosphere into the middleworld is not a relevant transport pathway. In addition, there is no apparent influence of convection in the middleworld during these flights. We test our hypothesis using a mixing model that takes tropospheric and stratospheric profiles of various tracers, and tries to match the composition of the air parcel that we sampled during CRYSTAL-FACE.

MIXING MODEL

How it works:

For a given flight, we vary the latitude of the initial stratospheric profile and the amount of descent (measured in units of potential temperature (PT)) of these profiles into the middleworld. We choose the latitude using tracer-tracer correlations, potential vorticity (PV) analysis, and 10-day isentropic back trajectories. From the amount of descent we shift the initial stratospheric profiles into the middleworld assuming diabatic descent. The initial tropospheric profile we use comes from the UTT, and is the same for all flights. Once the intial profiles are chosen, the model minimizes the difference between a linear combination of initial tropospheric and stratospheric air and the measured profile during CRYSTAL-FACE. The minimization is done by fitting different fractions of tropospheric and stratospheric components for each of the tracers simultaneously at each given time during the flight and comparing the linear combination to the corresponding measured values.

Tracers:

O_3, H_2O, CO_2, CO and NO_y.

Profiles used:

UTT profiles are as follows: for O_3, H_2O, CO, and NO_y we use average summertime tropical profiles; for CO_2 we use average summer values measured at Samoa and Mauna Loa and assume rapid ascent to 350 K followed by slow ascent of 0.5 K/day. Of these profiles, the largest uncertainties are in the H_2O profiles.

Stratospheric profiles are derived first using ozonesonde data between 20 and 58 degrees North and fitting the stratospheric profiles to PT. When we choose a starting latitude for the model, the ozone profile is calculated using the nearest ozonesonde location, and the remaining tracers are then calculated using tracer-O_3 correlations at the appropriate latitude derived using *in situ* measurements from the 1996 STRAT campaign. We use three different latitude bands for the tracers: 20-30 degrees, 30-45 degrees, 45-75 degrees.

Assumptions:

- Diabatic descent from the tropical stratosphere into the subtropical middleworld is very slow during the summertime due to small zonal mean residual vertical velocities.
- Initial tropospheric and stratospheric mixing ratios for each tracer have not changed significantly compared to present day values. For CO_2, however, we do account for the secular trend in the atmosphere and we increase STRAT values by 10.6 ppmv.
- High resolution *in situ* measurements of tracers during both CRYSTAL-FACE and STRAT have no longitudinal dependence.
- The five tracers used have long-lived behavior (e.g., no major chemical losses) during the 10-day back trajectory.

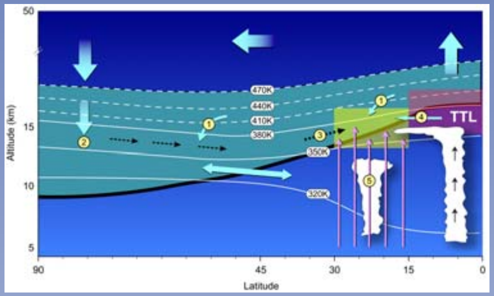

Figure 1. Transport mechanisms of air into the middleworld (yellow box): 1- Diabatic descent from the tropical stratosphere, 2- Diabatic descent in high latitudes, 3- Isentropic transport equatorward from higher latitudes, 4- Isentropic transport from the TTL, 5- Convection.

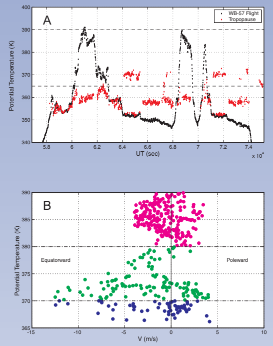

Figure 2.
(A) WB-57 Flight trajectory and tropopause location in potential temperature units on 20020711.

(B) Meridional winds measured aboard the WB-57 in the middleworld on 20020711.

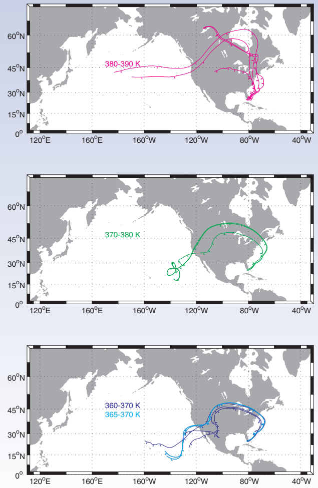

Figure 3. 10-day Isentropic back trajectories for air parcels between 380-390 K, 370-380 K, 365-370 K that were sampled on 20020711.

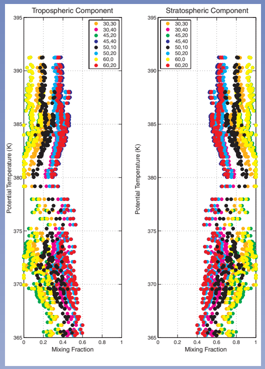

Figure 4. Mixing fractions using different input parameters as indicated in the legend to model the region above 365 K on 20020711. The same initial stratospheric profile is used for the entire region.

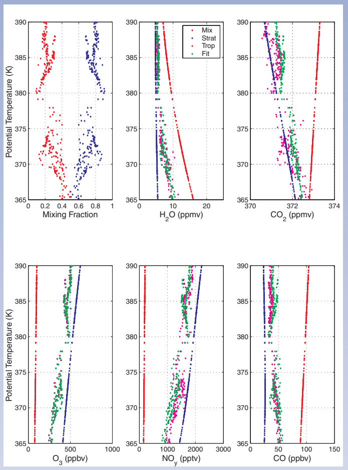

Figure 5. Output from the mixing model with initial tropospheric (red), stratospheric (blue), measured (magenta), and modeled (green) profiles, as well as the final mixing fraction of each component. Input parameters are latitude=50, PT descent=10 K for the region between 365 and 390 K on 20020711.

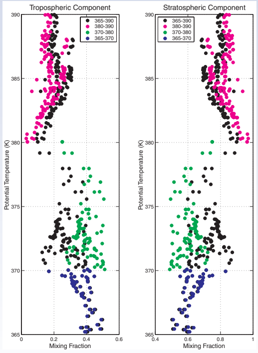

Figure 6. Best fits from the mixing model using the same initial stratospheric profile for the entire region (black dots), for the 365-370 K region only (blue dots), for the 370-380 K region only (green dots), and for the 380-390 K region only (magenta dots) using values listed in Table 1.

CASE STUDY: 20020711

- We choose the potential temperature region between 365 and 390 K where there is no apparent influence of convection and we assume transport of air into the middleworld to be quasi-isentropic (Figure 1).
- Potential Vorticity between 365 and 390 K is greater than 2 PVU, implying that the air in this region is entirely above the tropopause, which is in agreement with MTP tropopause measurements (Figure 2A).
- Meridional winds between 365 and 390 K measured by MMS aboard the WB-57 are predominantly equatorward (Figure 2B).
- 10-day isentropic back trajectories obtained using the Goddard Automailer show air parcels between 365 and 390 K coming from different latitudes (45 to 60 degrees North), but all of them follow an anticyclonic motion (Figure 3).

RESULTS

- We run the model using different latitudes and descent values and apply the corresponding initial stratospheric profile to the whole region. While we observe variability in the range of the results, all conditions show that the air in this region is predominantly stratospheric (Figure 4). We discriminate between conditions based on the goodness of the fit (f(x)) to each measured tracer (Figure 5).
- Using the same initial stratospheric profile assumes that the air had the same origin throughtout the entire region. We tested the validity of this assumption by finding the best fit to all our measured tracer profiles first. This happened at latitude=50 degrees North, and PT descent=10 K (combination A). We then broke down the region into three sub-regions: 365-370 K, 370-380 K, and 380-390 K and analyzed them individually. The best fit happened at the conditions listed in Table 1. Figure 6 shows the mixing fractions for all the combinations in Table 1. Even when we allow different origins for different PT regions, the model still suggests that the air is predominantly stratospheric in origin.

Combination	PT (K)	Latitude (°)	dPT (K)	f(x)
A	365-390	50	10	0.3693
B	365-370	45	30	0.0386
C	370-380	50	20	0.1185
D	380-390	60	5	0.1981

Table 1. Initial conditions used to obtain best fit to the measured data.

- The 10-day back trajectories (Figure 3) show that air parcels in the 365-390 K region traveled over different latitude ranges, which is more in agreement with the results from combinations B, C, and D.

CONCLUSIONS

- Our simple mixing model suggests that the air sampled on 20020711 between 365 and 390 K is predominantly of stratospheric origin, coming from latitudes higher than 45 degrees North.
- Both our model and the back trajectories show equatorward transport of air into the middleworld suggesting that air parcels at PT between 365 and 390 K can be influenced by quasi-stationary anticyclones.

FUTURE WORK

- Use Eulerian PV contours to check for consistency of our results with meteorological conditions.
- Explore the impact of different initial profiles, especially in the UTT, on the results of our model. In particular, use different approaches to determine the UTT H_2O profile.
- Generalize the model to account for other transport pathways. For instance, tracer-tracer correlations on 20020723 suggest that other pathways (i.e., quasi-isentropic transport from the UTT and diabatic descent from the tropical stratosphere into the middleworld) might be the dominant ones. Isentropic back trajectories for this flight are also very different from the ones for 20020711.